UNITED STATES PATENT APPLICATION

For

**THIN FILM PRECURSOR STACK FOR**

**MEMS MANUFACTURING**

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# THIN FILM PRECURSOR STACK FOR MEMS MANUFACTURING

## FIELD OF THE INVENTION

**[0001]** This invention relates generally to fabrication processes for microelectromechanical systems (MEMS) devices and more specifically to the manufacture of interferometric modulators.

## BACKGROUND OF THE INVENTION

**[0002]** An interferometric modulator is a class of MEMS (micro-electromechanical systems) devices which have been described and documented in a variety of patents including U.S. Patent Nos. 5,835,255, 5,986,796, 6,040,937, 6,055,090, and U.S. Pending Patent Application Nos. 09/966,843, 09/974,544, 10/082,397, 10/084,893, and 10/878,282, herein incorporated by reference. One of the key attributes of these devices is the fact that they are fabricated monolithically using semiconductor-like fabrication processes. Specifically, these devices are manufactured in a sequence of steps which combine film deposition, photolithography, and etching using a variety of techniques. More detail on these processes is described in patent application serial # 10/074,562 filed on February 12, 2002, and herein incorporated by reference.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0003]** Figure 1 shows a block diagram of an integrated MEMS processing facility;

**[0004]** Figure 2 shows a block diagram of a non-integrated MEMS processing facility;

**[0005]** Figure 3 shows a block diagram of a MEMS device which can be fabricated using a precursor stack of the present invention; and

**[0006]** Figures 4A to 4F show block diagrams of precursor stacks of the present invention, according to different embodiments.

## DETAILED DESCRIPTION OF THE INVENTION

**[0007]** In the following detailed description of embodiments of the invention, numerous specific details are set forth such as examples of specific materials, machines, and methods in order to provide a thorough understanding of the present invention. It will be apparent, however, to one skilled in the art that these specific details need not be employed to practice the present invention. In other instances, well known materials, machines, or methods have not been described in detail in order to avoid unnecessarily obscuring the present invention.

**[0008]** A common characteristic of processes for manufacturing MEMS devices is that they begin with the deposition of a stack of thin films which are crucial to the operation and subsequent fabrication of the device. These precursor films are useful in the fabrication of a broad variety of MEMs devices including interferometric modulators, and their deposition can occur as a part of a larger process to manufacture the MEMS device. In one embodiment of the present invention the films are deposited separately in a stand alone facility to form a precursor stack, which is then sent to multiple facilities which complete the processing. The primary benefit is that the stand alone facility can be optimized to produce these films or precursor stacks at very high throughputs that allow for economies of scale not possible in an integrated factory, i.e., one that does both the deposition and post-deposition processing. Furthermore, since the technology development of the precursor stack occurs at the stand alone facility, entities which desire to perform the subsequent processing steps are faced with a lower technological barrier to entry.

**[0009]** Patent Application No.10/074,562 herein incorporated by reference describes a prototypical fabrication sequence for building interferometric modulators. In general, interferometric modulator fabrication sequences and categories of sequences are notable for their simplicity and cost effectiveness. This is due in large part to the fact that all of the films are deposited using physical vapor deposition (PVD) techniques with sputtering being the preferred and least expensive of the approaches. Part of the simplicity derives from the fact that all interferometric modulator structures, and indeed many other planar MEMS structures are bound by the fact that they require a lower electrode, an insulating structure to prevent shorting, a sacrificial material, and an actuatable or movable structure. An insulating structure differs from a film in that it is not continuous in its form but by mechanical means is able to prevent electrical contact through its body. This fact presents an opportunity in that a subset of these films, a precursor stack comprising one or more of the lower electrode, insulating structure, the sacrificial layer, and optionally an actuatable structure may be manufactured separately and in advance of the actuatable structure or structures.

**[0010]** Figure 1 of the drawings provides a block diagram of an integrated MEMS fabrication facility 102. A precursor film deposition tool 100, comprises a single or series of deposition tools which are configured to deposit these films using one or more deposition techniques, e.g., sputtering. The films are deposited on a suitable carrier substrate, which could be glass or plastic, for example, depending on the application, and subsequently transported to micro-machining loop 104. Here, and as

described in the aforementioned patent applications, a sequence of repeated steps, such as etching, patterning, and deposition, are performed and serve to define the actuatable structure of the MEMS device.

**[0011]** Figure 2 of the drawings shows a non-integrated MEMS processing facility. Referring to Figure 2, a pre-cursor facility 200 contains only a precursor film deposition tool 100 which is equivalent to that described in Figure 1, hence the use of the same reference numeral. The facility 200 is capable of providing variations on both precursor film type and substrate size. After the deposition, the substrates are containerized and shipped as appropriate to one or more processing facilities indicated by reference numeral 202. These facilities then perform the machining steps as required for the particular MEMS product that they are designed to produce.

**[0012]** Figure 3 shows a schematic drawing of a simple MEMS device which can be fabricated using a precursor stack of the present invention. In this case an actuatable membrane304, is supported on posts 306. Films 302 comprise materials which at a minimum provide a lower electrode and an insulating structure, though other functions, as will be discussed, may be incorporated. The entire assembly resides on a substrate 300.

**[0013]** Figures 4A to 4F of the drawings show block diagrams of precursor stacks in accordance with different embodiments of the invention. In Figures 4A to 4F, the same reference numerals have been used to identify the same or similar features/components.

**[0014]** Figure 4B shows a block diagram of a generalized precursor stack 400A that includes conductor stack or structure 404, an insulator layer 406, and a sacrificial material layer 408. All the films reside on a substrate 402. The conductor stack 404may comprise a single metal, a conductive oxide or polymer, a fluoride, a silicide or combinations of these materials. The exact composition of the conductive stack is determined by the requisite electrode properties of the MEMS device to be manufactured. The insulator 408, can be any one or a combination of a variety of insulating materials which include but are not limited to oxides, polymers, fluorides, ceramics, and nitrides. The sacrificial material 408, may include, for example, a single layer of materials such as silicon, molybdenum, or tungsten which are all etchable by XeF2, which is a process etch gas that has been described in prior patents. Other materials are possible subject to the compatibility of the etching medium to the materials and structures which must remain. Thicknesses vary according to the requisite behavior of the final device.

**[0015]** Figure 4B shows a block diagram of a precursor stack 400B designed for use in the fabrication of an interferometric modulator device. The stack 400B includes a conductor stack 404, the composition of which has been described above. Suitable metals for the conductor stack 404 in the present case include glossy metals such as Chromium, Tungsten, Molybdenum, or alloys thereof. The conductor stack 404 may have a thickness of up to 150 angstroms. Transparent conductors suitable for use in the conductor stack 404 include indium tin oxide (ITO), zinc oxide (ZnO), and titanium nitride (TiN). Typical thicknesses for the transparent conductors range

from 100 to 800 angstroms. The conductor stack 404 resides on a transparent compensating oxide layer 410, in one embodiment. The oxide layer 410 may be of a metallic oxide, such as zirconia (ZrO2) or hafnia (HfO2), which have a finite extinction coefficient within the visible range. The compensating oxide layer 410 is an optional film for all the designs discussed in this patent application. Typical thicknesses for the oxide layer 410 range from 100 to 800 angstroms. It should be noted that the positions of the conductor stack 404 and the compensating oxide layer 410 are interchangeable with only subtle changes in the optical behavior. This design, however, can be considered an embedded optical film design since the metal, which plays the primary optical function, resides on the side of insulator layer 406, opposite that of the sacrificial layer 408. The insulator layer 406, may comprise a silicon dioxide film with a thickness ranging from 280 to 840 angstroms for good black states, although other thicknesses are useful for different interference modulator operational modes. Other oxides or combinations of oxides are possible as well. The sacrificial layer 408 may include a single layer of materials such as silicon, molybdenum, tungsten, for example, which are all etchable by XeF2, a process etch gas which has been described in prior patents. For the stack 400B, the thickness of the layer 408 may vary from 1000, to 7000 angstroms.

**[0016]** Figure 4C shows a block diagram of a precursor stack 400C, in accordance with another embodiment. In this case, the conductor stack 404 does not perform any optical functions. Instead, a separate optical film 412 performs the optical function. The optical film 412 is separated from the conductor stack 404 by an insulator film or

structure 414. This design allows for high quality white states to be achieved when the actuatable membrane is driven. In this case the optical film 412 does not serve as a conductor. It is the transparent conductor stack 404 which functions as a conductor. An ancilliary insulator film or structure which is not shown in Figure 4C but which is similar to the insulator layer 406 of Figure 4B, may reside between the sacrificial layer 408 and the optical film 412, in some embodiments. The thickness of the insulator film or structure may be less than 100 angstroms for this design.

**[0017]** Figure 4D shows an embodiment 400D of a precursor stack, known as a buried optical film design. In this case, an optical film 412, resides over an optical compensation film 410, which resides below an insulator film/structure 406. A transparent conductor film or film stack 404, follows and is capped by an additional oxide layer 416, and a sacrificial film layer 408. One advantage of the stack 400D is that it allows for the effective optical distance between the optical film 412 and the mechanical film to be large while allowing the driving voltages to remain small. This is because the driving voltages are significantly determined by the distance between the conductor and the actuatable membrane.

**[0018]** Figure 4E shows a precursor stack 400E which includes a multi-layer etch stop stack 418 incorporated instead of a single layer sacrificial film. This 418 stack provides a convenient means for predefining the heights for multiple actuatable structures to be defined during subsequent micro-machining processes. In one embodiment, the stack 418 comprises at least two materials which can be etched using the same release etch, but can utilize alternative and different etch chemistries

so that one material may act as an etch stop for the other. One example would be a combination of molybdenum and silicon that are both etchable in XeF2. However, a phosphoric based wet etchant may be used to etch molybdenum without attacking silicon, and a tetra-methyl-ammonium hydroxide (TMMA) which may be used to etch silicon without etching molybdenum. Many other combinations exist and can be identified and exploited by those skilled in the art. Further, it should be noted that the etch stop stack may be applied to any of the previously defined precursor stacks in place of the single sacrificial layer.

**[0019]** Figure 4F of the drawings shows an embodiment 400F of a precursor stack The precursor stack 400F includes a mechanical structural material 420. Using proper micro-machining techniques and sequences, a functioning MEM device may be fabricated using the precursor stack 400F using only patterning and etching. Thus, during post-processing of the precursor stack 400F no deposition is required. This means that a post-processing facility such as the facility 202 (see Figure 2) does not require capital investment in deposition tools. The material 420 may comprise any number of materials, including but not limited to metals, polymers, oxides, and combinations thereof, whose stress can be controlled.